Appendix F

Effect of Varying DAB Levels on FM Analog Compatibility

1. Overview

Of paramount importance in the design of a viable IBOC system is the compatibility of the new digital signals with existing analog service. USADR is carefully investigating the optimal spectral placement and power levels of its FM DAB sidebands to ensure superior digital audio performance while minimizing the impact to existing analog signals. Toward this end, USADR has performed a number of laboratory experiments to measure the degradation of an analog FM signal in the presence of hybrid IBOC sidebands, first adjacent hybrid IBOC signals, and selective fading. In particular, the following tests were performed using three representative, commercial FM receivers:

- Analog Deterioration. This test measures the signal strengths at which the candidate receivers begin to degrade and fail in the existing analog environment. Besides setting baseline analog performance, it provides a useful barometer for evaluating digital coverage.

- Comparison of Analog Co-Channel and Digital First Adjacent Interference. This test compares desired analog signal compatibility with an existing analog co-channel to the compatibility of a first adjacent hybrid IBOC interferer whose DAB sidebands present equivalent co-channel interference to the desired signal. It provides motivation for investigating the effects of increasing DAB power above the –22 dB_{host} baseline.[1]

- Host Compatibility. This test measures the degradation introduced to the host analog signal by its IBOC DAB sidebands. Besides measuring the analog audio SNR of a *baseline IBOC* signal, the test also finds the levels of the DAB sidebands at which the candidate receivers begin to degrade and fail.

- First adjacent Compatibility. This test measures the degradation introduced to the desired analog signal by a first adjacent hybrid IBOC signal. In addition to measuring the analog audio SNR of the desired IBOC signal in the presence of a *baseline IBOC* first adjacent interferer, the test also finds the levels of the adjacent DAB sidebands at which the candidate receivers begin to degrade and fail.

This report will describe the test procedures, present the results, and draw conclusions on the impact of varying DAB power level on existing analog service.

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[1] Second adjacent channel compatibility is addressed in Appendix E.

2. Procedures

2.1 Definitions

A number of terms used regularly throughout this report are defined below.

- The *baseline DAB* signal has total power 22 dB below the total power in the analog host FM signal.
- The *baseline FM* signal consists of a pilot channel and a main audio channel modulated by *processed pop music*. (There are no SCAs).
- The combination of *baseline DAB* and *baseline FM* signals produces the *baseline IBOC* signal.
- The *processed pop music* is The Wallflowers, "I Wish I Felt Nothing". The audio processing is provided by an Orban Optimod 8200 with a "Rock-Dense" setting.
- A *quiet FM* signal is defined as modulation by the pilot only (10%), with no left or right audio inputs.
- A *maximum first adjacent channel* is defined as a *baseline IBOC channel* which is transmitted 200 kHz from the desired channel, with total power 6 dB below the total power of the desired FM channel, but modulated with *processed pink noise*.
- *TOA* is defined as the threshold of audibility, which is the point at which the analog signal of interest begins to exhibit audible degradation.
- *POF* is defined as the point of failure, where the analog signal of interest degrades to a point where the listener would tune to another station.
- *Processed pink noise* is simply white Gaussian noise that has been filtered with a 3 dB/octave rolloff and is subsequently processed using an Orban FM Optimod 2200D. The pink noise was generated by the Audio Precision System Two 2322. The Optimod processing settings were :

EQ		
↓ →	30HzHPF = In	
	LOW BASS = +2 dB	
	HF ENHANCE = +2	
FULL CONTROL		
↓ →	GATE THR = -40 dB	
	AGC = On	
	AGC DRIVE = 10 dB	
	2B DRIVE = 12 dB	
	REL TIME = +1 dB/sec	
	BASS COUPL = 0 %	
	HF LIMIT = 0.0	
	CLIPPING = +0.5	
	FINAL CLIP = 0.0	

2.2 General Methodology

To verify compatibility of FM IBOC DAB with existing analog service, USADR randomly selected receivers from each of three major classes of commercially available FM radios:

(1) Home HiFi – Yamaha HTR-5130
(2) Car Stereo – Pioneer KEH-P2800
(3) Boombox – Philips Magnavox AZ1020

An RF signal was delivered to each receiver over coaxial cable through a BNC connector.[2] TOA and POF were determined by subjective, critical listening tests. Headphones were used for listening to the home HiFi; however, speakers were used for listening to the car stereo and boombox, since this better reflects actual listening habits.

The host and first adjacent analog FM signals were generated by a Harris THE-1 FM exciter and/or Sencore SG-80 FM Stereo Analyzer, and the DAB digital sidebands were generated using a USADR FM IBOC DAB Exciter.

Audio signal-to-noise ratio (SNR) was measured using an HP89440A Vector Signal Analyzer (VSA). The SNR was measured by the VSA in a 150 Hz bandwidth around a 1 kHz audio tone at the left or right audio channel output of the receiver. The audio SNR measured by the VSA was then scaled to a 15 kHz bandwidth.

Only the car stereo was tested in selective fading, since the other receivers are not typically used in a mobile environment. The Electronic Industries Association (EIA) 9-

[2] The boombox was modified to accept the signal in this manner.

ray "Urban Fast" Rayleigh multipath fading profile was used.[3] This profile is shown in the table below.

Urban Fast Rayleigh Multipath Profile			
Ray	**Delay (microseconds)**	**Doppler (Hz)**	**Attenuation (dB)**
1	0.0	5.2314	2.0
2	0.2	5.2314	0.0
3	0.5	5.2314	3.0
4	0.9	5.2314	4.0
5	1.2	5.2314	2.0
6	1.4	5.2314	0.0
7	2.0	5.2314	3.0
8	2.4	5.2314	5.0
9	3.0	5.2314	10.0

This fading profile was generated in the laboratory using a Noise/Com MP2700 Multipath Fading Emulator. Both desired and interfering signals were independently faded per this profile.

To cover a wide range of signal levels, the tests were performed with desired signal strengths of 34, 54, and 74 dBu. Conversion from dBu into dBm at the receiver input is as follows. Assuming a mid-band carrier frequency of 100 MHz and a dipole antenna of unity gain (due to ground-plane losses, etc.), electric field intensity E (V/m) can be converted to carrier power C (W) at the input to the receiver using

$$C = \frac{E^2}{120\pi} A_e$$

where

$$A_e = \frac{\lambda^2}{4\pi} G$$

In this case, $A_e = 0.716\ m^2$ is the effective aperture of the unity-gain dipole antenna. Using this formula, a 54 dBu field strength corresponds to a –63.2 dBm carrier power. Likewise, 74 dBu and 34 dBu field strengths correspond to –43.2 dBm and –83.2 dBm carrier powers, respectively.

In addition, to encompass a broad range of ambient noise levels, the tests were performed in Gaussian noise environments of 10,000K and 100,000K. To convert from noise temperature in degrees K to noise power in dBm/Hz, the following formula is used:

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[3] In 1993, the EIA conducted multipath characterization tests in Salt Lake City, and subsequently created four "profiles" that are descriptive of the multipath environment. The urban fast profile simulates driving at approximately 35 mph through a city street.

$$N = 10\log_{10}(kT) + 30$$

where N is the noise power in dBm/Hz, κ is Boltzmann's constant in Joules per degrees Kelvin (1.38×10^{-23}), and T is the noise temperature in degrees Kelvin. The resulting noise power can then be scaled to the desired measurement bandwidth by adding $10 * \log_{10}$(bandwidth in Hz). Thus, in a 150 kHz measurement bandwidth, a noise temperature of 10,000K corresponds to a noise power of –106.8 dBm, and a noise temperature of 100,000K corresponds to a noise power of –96.8 dBm. The noise was produced using a Noise/Com Gaussian noise generator, and was summed with the signal just prior to the receiver input.

2.3 Detailed Test Procedures

2.3.1 Analog Deterioration

This test records the signal strengths at which the TOA and POF are reached for each of the receivers when receiving a purely analog signal. The test was performed with ambient noise temperatures of 10,000K and 100,000K, using both *quiet FM* and *baseline FM* signals. Since the results are subjective, seven different listeners were used to estimate TOA and POF. The test setup is shown in Figures F-1 and F-2. The test is performed as follows:

(a) Transmit a 74 dBu *quiet FM* signal at a 10,000K noise temperature.

(b) Decrease the level of the signal until TOA. Record the associated FM signal level.

(c) Transmit a 74 dBu *baseline FM* signal at a 10,000K noise temperature.

(d) Decrease the level of the signal until TOA and POF. Record the associated FM signal levels.

(e) Repeat (a) through (d) at a 100,000 K noise temperature.

(f) Repeat (a) through (e) for all FM receivers under test.

(g) Repeat (a) through (e) in the fading environment for the Pioneer car stereo.

(h) Repeat (a) through (g) using numerous listeners.

2.3.2 Comparison of Analog Co-Channel and Digital First Adjacent Interference

Maximizing the coverage of its digital signal is of prime importance to USADR. The extent of digital coverage is directly related to the power of the digital sidebands.

Unfortunately, increasing the level of the digital portion of the IBOC signal expands digital coverage with the potential of increased interference to analog signals.

According to FCC rules, properly spaced Class B FM stations are protected to the 54 dBu contour from co-channel interference exceeding 34 dBu in 50 percent of the locations for 10 percent of the time. [4] This implies that 90 percent of the time at the 54 dBu contour, the co-channel D/U exceeds 20 dB. In addition, properly spaced Class B stations are protected to the 54 dBu contour from first adjacent channel interference exceeding 48 dBu in 50 percent of the locations for 10 percent of the time. Based on this information, some observations can be made regarding the character of adjacent-channel hybrid IBOC interference.

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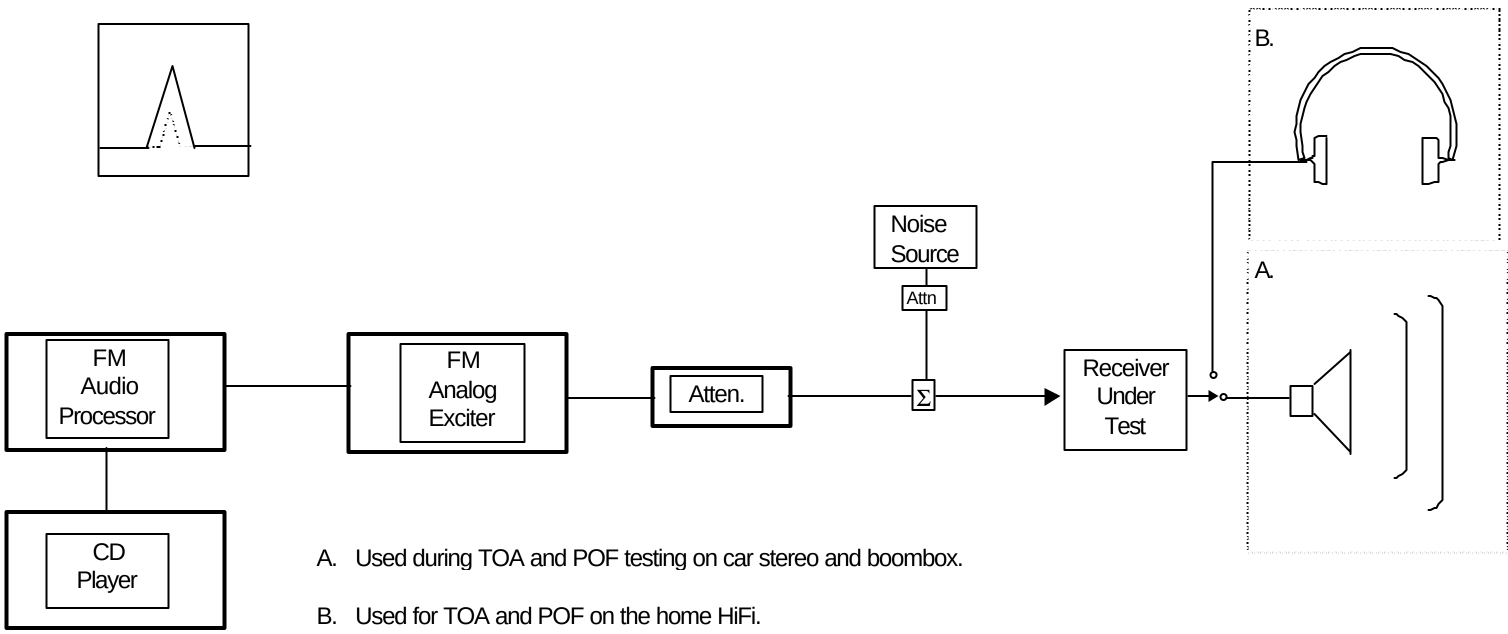
[4] The contours assume the Bullington field strength prediction technique.



A. Used during TOA and POF testing on car stereo and boombox.

B. Used for TOA and POF on the home HiFi.

Figure F-1 - Analog Deterioration Test Setup without Fading

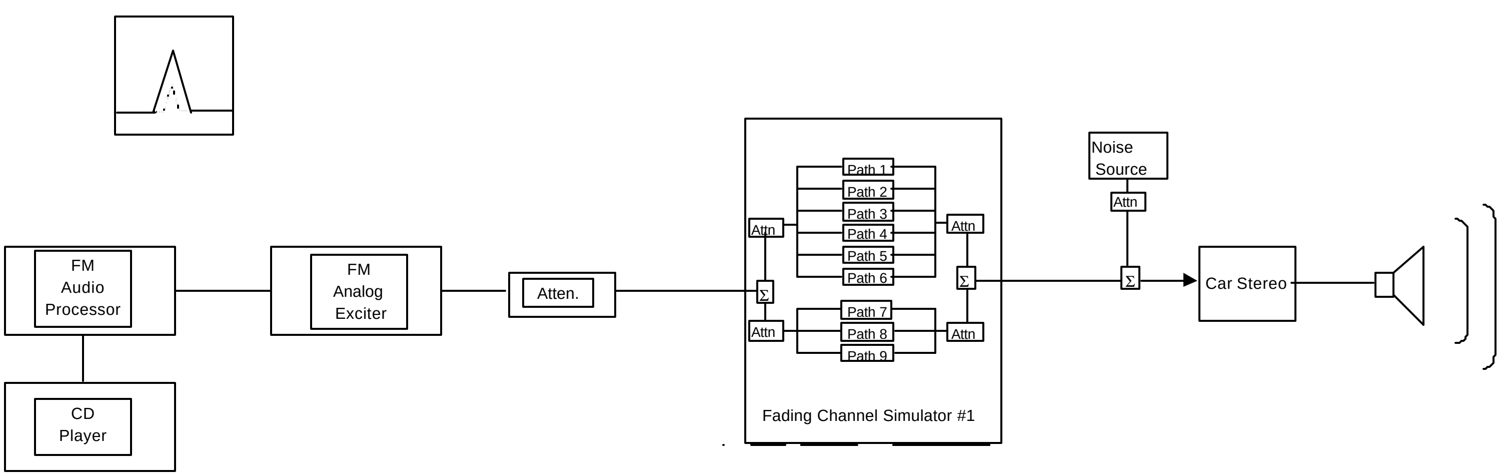


Figure F-2 - Analog Deterioration Test Setup with Fading

Perhaps the most significant challenge to compatibility of IBOC signals with existing analog service is the interference introduced by IBOC first adjacents. As shown in Figure F-3, the lower DAB sideband of an upper first adjacent hybrid IBOC signal lies under the desired analog signal; to the desired analog signal, it is effectively co-channel interference.

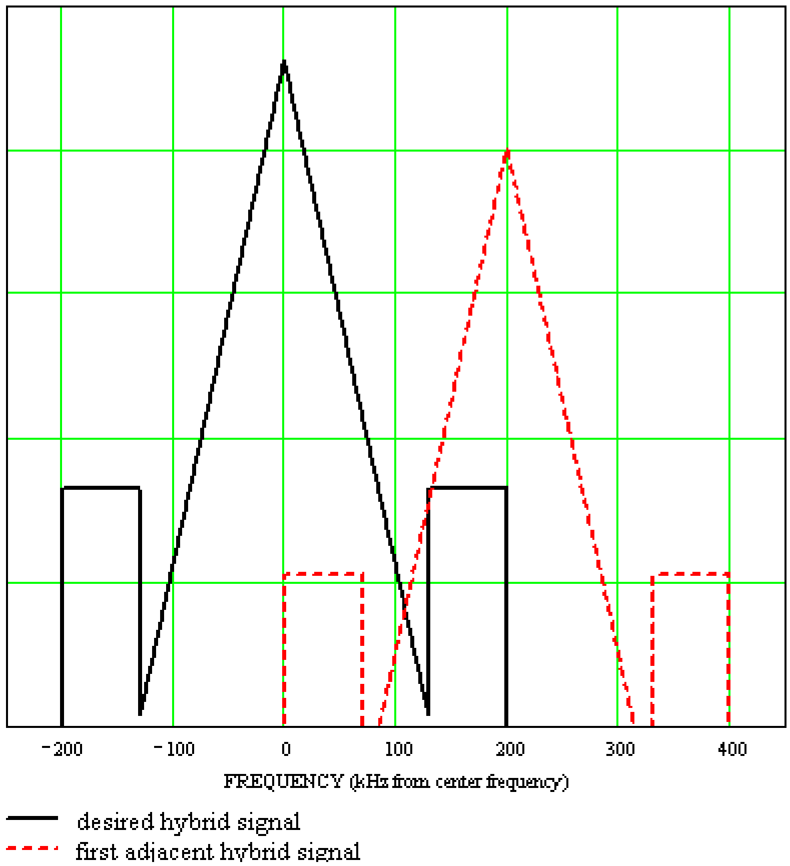


Figure F-3 – Hybrid First Adjacent Interference at a D/U of 6dB

For a properly spaced Class B FM station at its protected 54 dBu contour, a maximum co-channel would introduce interference 20 dB below the level of the desired signal. Since the maximum first adjacent analog signal at this contour is constrained to be 6 dB below the level of the desired signal, its *baseline IBOC* DAB sideband (-25 dB_{host} per sideband) would act as a co-channel interferer with total power 31 dB below the desired analog signal (host – 6 – 25 = host - 31). Thus, it would appear that the power of the DAB sidebands in the *baseline IBOC* signal could actually be increased by 11 dB without introducing more interference than that allowed by existing co-channels. Of course, the spectral shape and modulation of the analog co-channel interferer differs greatly from that of a first adjacent DAB sideband; as a result, laboratory testing was performed to compare the effects.

This test measures the degradation introduced to the desired analog signal by a –20 dB analog co-channel, and compares it to the degradation introduced by a –6 dB first adjacent hybrid IBOC signal with total DAB power of –11 dB_{host}. It first measures the audio SNR of the desired host analog signal with and without *baseline DAB*. It then measures the audio SNR of the desired analog signal in the presence of each interferer (analog co-channel and IBOC first adjacent), and subjectively compares the audibility of the interference.[5] This test is performed on the car stereo at a 54 dBu signal strength in a 10,000K noise environment. The test setup is shown in Figure F-4. The test is performed as follows:

(a) Transmit a 54 dBu, 1 kHz-tone-modulated FM signal at a 10,000K noise temperature. Measure and record the audio SNR.

(b) Add *baseline DAB* (-22dB_{host}) to the host FM signal and measure and record the audio SNR.

(c) Add an analog *baseline FM* co-channel interferer whose power is 20 dB below that of the desired signal. Measure and record the audio SNR.

(d) Replace the FM co-channel interferer with a *maximum first adjacent channel*. Increase the level of its DAB sidebands by 11 dB (to –11 dB_{host} total DAB power), and measure and record the audio SNR.

(e) Transmit a 54 dBu *baseline IBOC* signal at a 10,000K noise temperature. Add an analog *baseline FM* co-channel interferer whose power is 20 dB below that of the desired signal, and record the subjective audio quality.

(f) Replace the FM co-channel interferer with a *maximum first adjacent channel*. Increase the level of its DAB sidebands by 11 dB (to –11 dB_{host} total DAB power), and record the subjective audio quality.

5 The subjective analysis was performed by one listener.

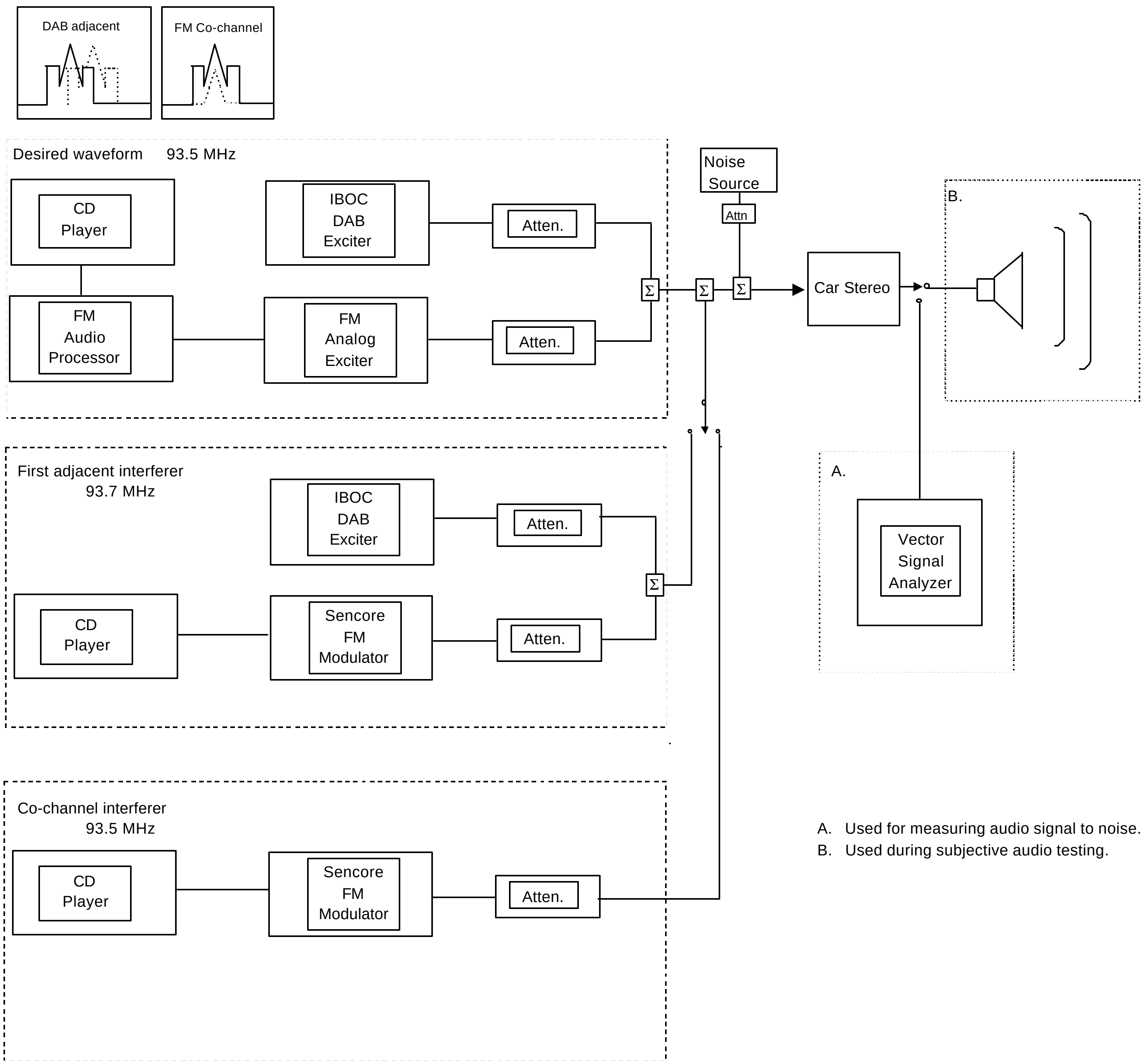


Figure F-4 - Comparison of Analog Co-channel and Digital First Adjacent Interference Test Setup

2.3.3 Host Compatibility

This test measures the degradation introduced to the analog host signal by its IBOC DAB sidebands. It measures the audio SNR of the host FM signal with no DAB sidebands, with DAB sidebands whose total power is 22 dB below the total power in the host FM signal, and with DAB sidebands whose total power is 11 dB below the total power in the host FM signal. The test also records the levels of the DAB sidebands at which the TOA and POF are reached for each of the receivers, with both *quiet FM* and *baseline FM* signals.[6] The test is performed at FM signal strengths of 34 dBu, 54 dBu, and 74 dBu, and with ambient noise temperatures of 10,000K and 100,000K. The test setup is shown in Figures F-5 and F-6. The test is performed as follows:

(a) Transmit a 74 dBu, 1 kHz-tone-modulated FM signal at a 10,000K noise temperature. Measure and record the audio SNR.

(b) Add *baseline DAB* (-22dB_{host}) to the host FM signal and measure and record the audio SNR.

(c) Increase the total power in the DAB sidebands to –11dB_{host} and measure and record the audio SNR.

(d) Transmit a 74 dBu *quiet FM* signal at a 10,000K noise temperature.

(e) Add DAB sidebands and increase their level until TOA. Record the associated DAB signal level.

(f) Transmit a 74 dBu *baseline IBOC* signal at a 10,000K noise temperature. Turn the DAB on and off and record whether the presence of DAB is audible.

(g) Adjust the level of the DAB until TOA and POF. Record the associated DAB signal levels.

(h) Repeat (a) through (g) for all remaining permutations of noise temperature and signal strength (10,000 K, 100,000 K, 34 dBu, 54 dBu, and 74 dBu).

(i) Repeat (a) through (h) for all FM receivers under test.

(j) Repeat (d) through (h) in the fading environment for the Pioneer car stereo.

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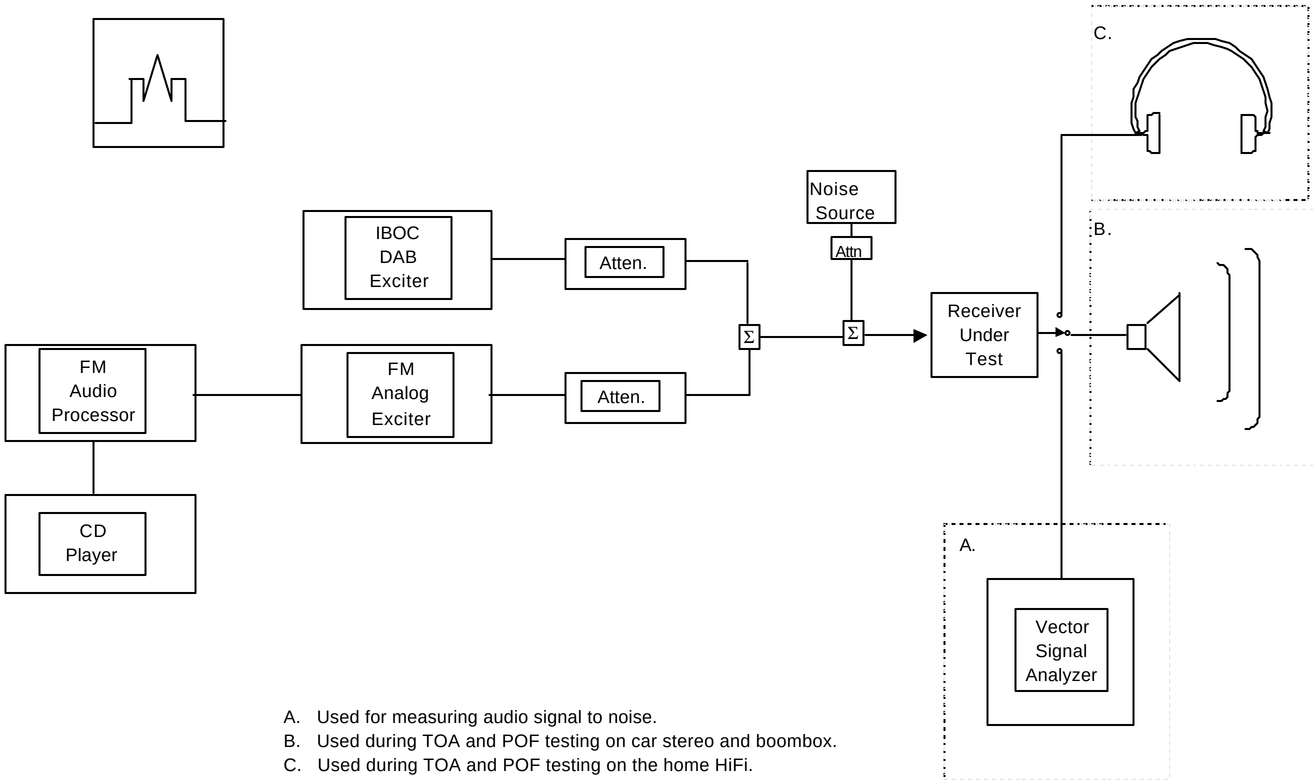
[6] The subjective analysis was performed by one listener.



A. Used for measuring audio signal to noise.
B. Used during TOA and POF testing on car stereo and boombox.
C. Used during TOA and POF testing on the home HiFi.

Figure F-5 - Host Compatibility Test Setup without Fading

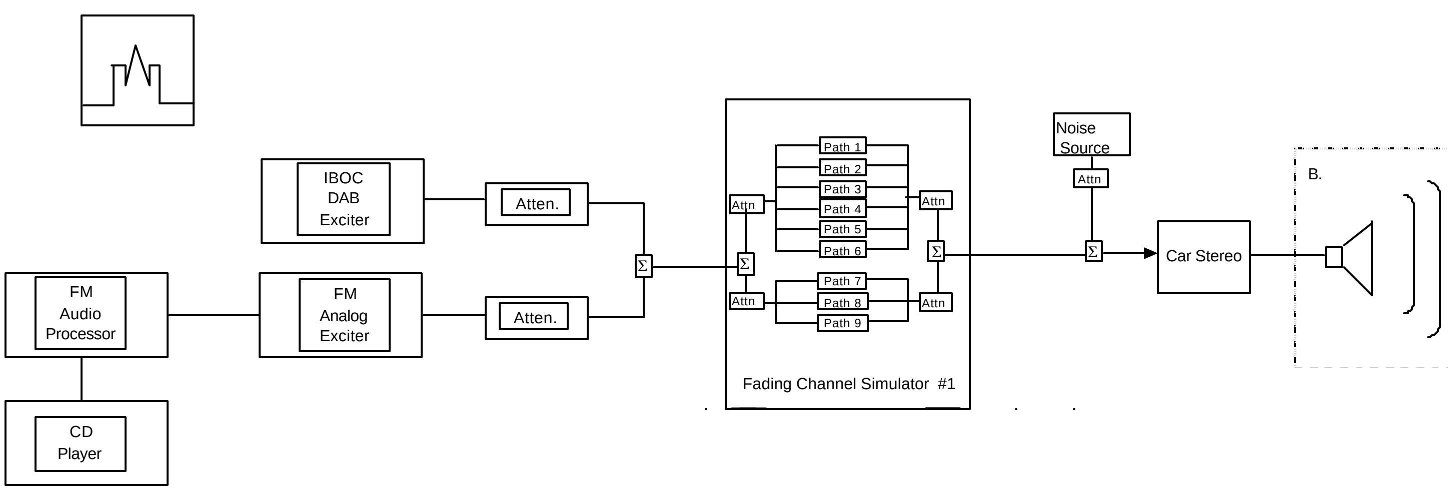


Figure F-6 - Host Compatibility Test Setup with Fading

2.3.4 First adjacent Compatibility

This test measures the degradation introduced to the desired analog signal by a first adjacent hybrid IBOC signal. It measures the analog audio SNR of the desired IBOC signal in the presence of a *maximum first adjacent channel*, with the adjacent DAB turned on and off. It also assesses the audibility of the *maximum first adjacent channel* when listening to both *quiet FM* and *baseline FM* desired signals. In addition, the test records the levels of the first adjacent DAB sidebands (with a fixed host) at which the TOA and POF are reached for each of the receivers, with both *quiet FM* and *baseline FM* desired signals.[7] The test is performed at a 54 dBu signal strength, with ambient noise temperatures of 10,000K and 100,000K. The test setup is shown in Figures F-7 and F-8. The test is performed as follows:

(a) Transmit a 54 dBu, 1 kHz-tone-modulated FM signal with *baseline DAB* (-22dB_{host}) at a 10,000K noise temperature. Add a *maximum first adjacent channel*. Measure and record the audio SNR.

(b) Turn the adjacent DAB off and measure and record the audio SNR.

(c) Toggle the adjacent DAB on and off and record whether its presence is audible.

(d) Transmit a 54 dBu *quiet FM* signal with *baseline DAB* (-22dB_{host}) at a 10,000K noise temperature. Add a *maximum first adjacent channel*. Adjust the level of the adjacent DAB sidebands until TOA. Record the associated adjacent DAB signal level.

(e) Transmit a 54 dBu *baseline IBOC* signal at a 10,000K noise temperature. Add a *maximum first adjacent channel*. Toggle the adjacent DAB on and off and record whether its presence is audible.

(f) Adjust the level of the adjacent DAB sidebands until TOA and POF. Record the associated adjacent DAB signal levels (relative to their host).

(g) Repeat (a) through (f) at a noise temperature of 100,000K.

(h) Repeat (a) through (g) for all FM receivers under test.

(i) Repeat (e) with a *quiet FM* desired signal in the fading environment for the Pioneer car stereo, at noise temperatures of both 10,000K and 100,000K.

(j) Repeat (d) through (g) in the fading environment for the Pioneer car stereo.

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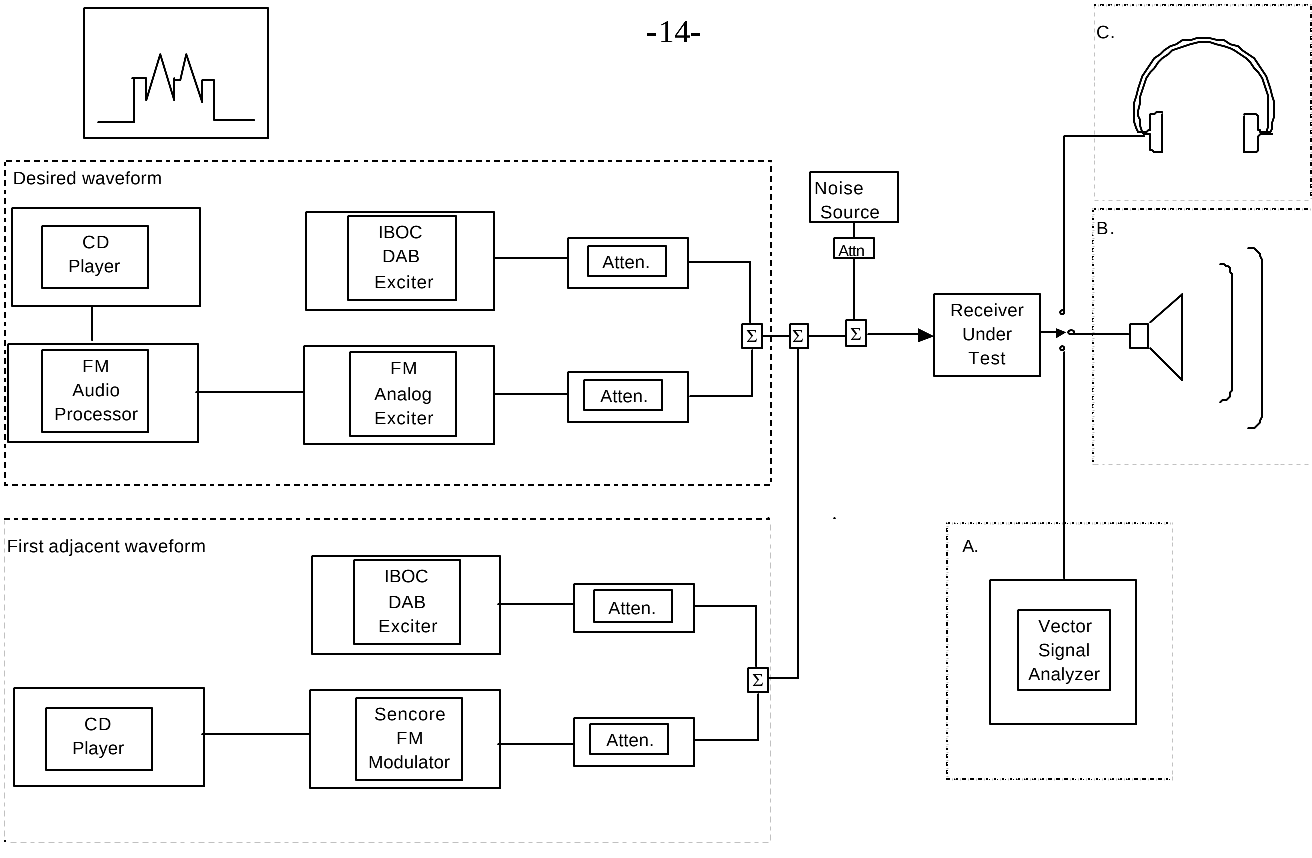
[7] The subjective analysis was performed by one listener.



A. Used for measuring audio signal to noise.
B. Used during TOA and POF testing on car stereo and boombox.
C. Used for TOA and POF testing on the home HiFi.

Figure F-7 - First-adjacent Compatibility Test Setup without Fading

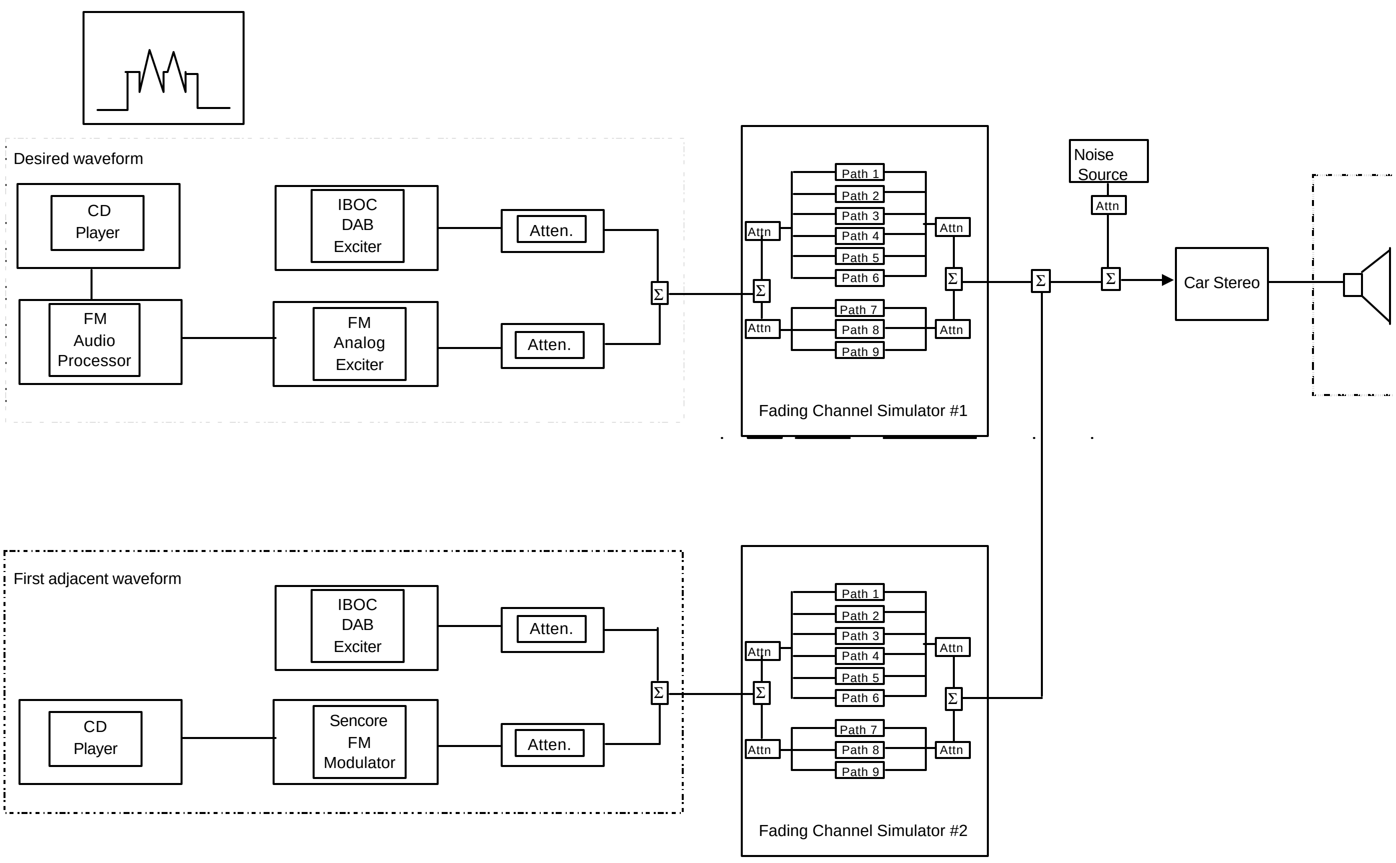


Figure F-8 - First-Adjacent Compatibility Test Setup with Fading

3. Results

These tests are important because they not only indicate compatibility of the *baseline IBOC* signal with existing analog service, but they also provide insight into the optimal signal level at which the DAB should be set.

3.1. Analog Deterioration

This test measured the signal strengths at which the representative receivers begin to degrade and ultimately fail in the existing analog environment. This information provides an important benchmark for digital coverage.

Since the results of this test are purely subjective, seven different listeners were used. For a given receiver and environment, Figures F-9 through F-16 plot the perceived TOAs and POFs of all listeners, as well as the average across all listeners. Figure F-17 plots the average TOAs and POFs across all listeners for each receiver and environment.

Figures F-9 through F-16 indicate that the largest variability among listeners occurred when estimating the music TOA. This may be attributed to the ability of some listeners to perceive imperfections which others simply cannot. The source of the variability in POF lies in an individual's tolerance for badly degraded music; however, with the exception of perhaps one particularly discriminating listener, this variability is remarkably small. This is important, since the average POF can then be reliably used to determine useful coverage area.

Figure F-17, which displays results averaged across all listeners, provides several insights into current analog reception. First, the large gap between quiet TOA and music TOA indicates that signal imperfections which might easily be heard with a quiet signal are effectively masked by audio. Second, as might be expected, a 10 dB increase in noise level (from 10,000K to 100,000K) provides roughly a 10 dB loss in coverage. Third, although the TOA is much higher in a fading environment, the POF is degraded by less than 10 dB. Fourth, for a given environment, there is little difference in receiver performance – less than 5 dB across all receivers.

Most importantly, the "Music POF" results of Figure F-17 indicate that the useful coverage area of current analog radio – that is, the signal strength at which the point of failure is reached – lies between 25 dBu and 35 dBu in a 10,000K environment, and between 40 dBu and 45 dBu in a 100,000K environment.[8]

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[8] USADR FM hybrid IBOC DAB field test data indicates that this is indeed the case. See Appendix H.

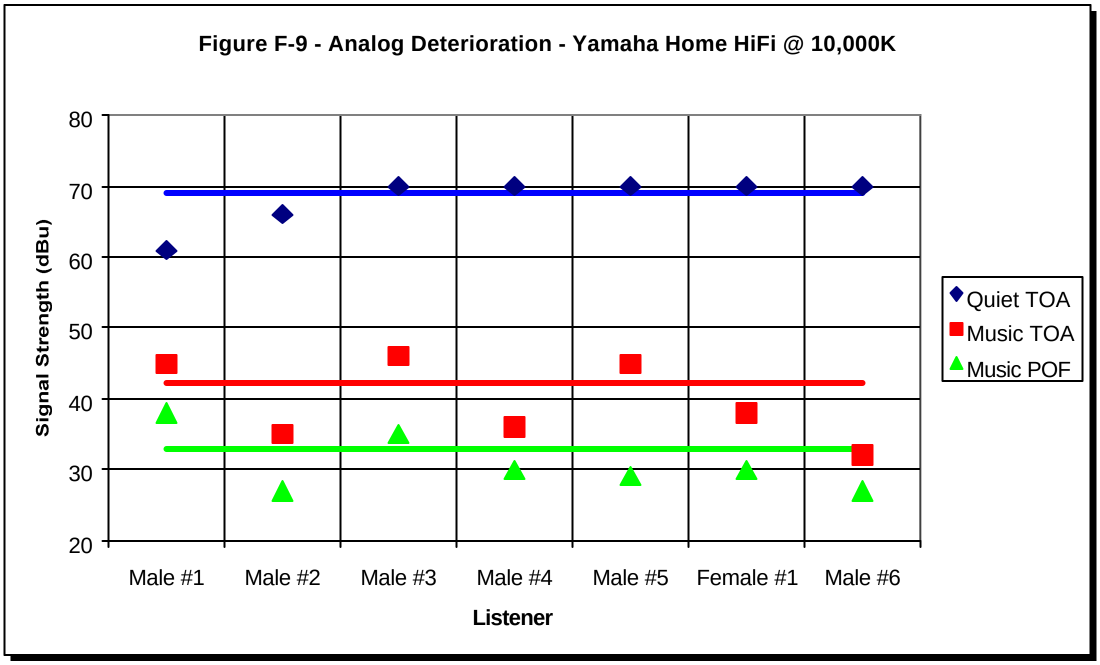


Figure F-9 - Analog Deterioration - Yamaha Home HiFi @ 10,000K
Signal Strength (dBu)
80
70
60
50
40
30
20
Male #1
Male #2
Male #3
Male #4
Male #5
Female #1
Male #6
Listener
Quiet TOA
Music TOA
Music POF

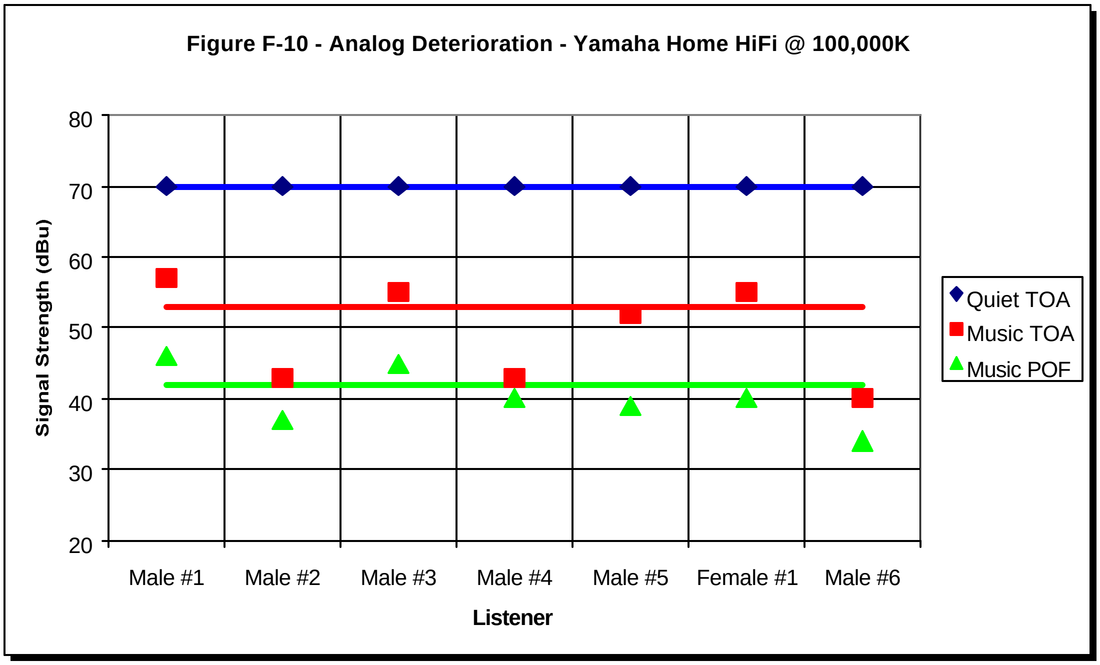


Figure F-10 - Analog Deterioration - Yamaha Home HiFi @ 100,000K
Signal Strength (dBu)
80
70
60
50
40
30
20
Male #1
Male #2
Male #3
Male #4
Male #5
Female #1
Male #6
Listener
Quiet TOA
Music TOA
Music POF

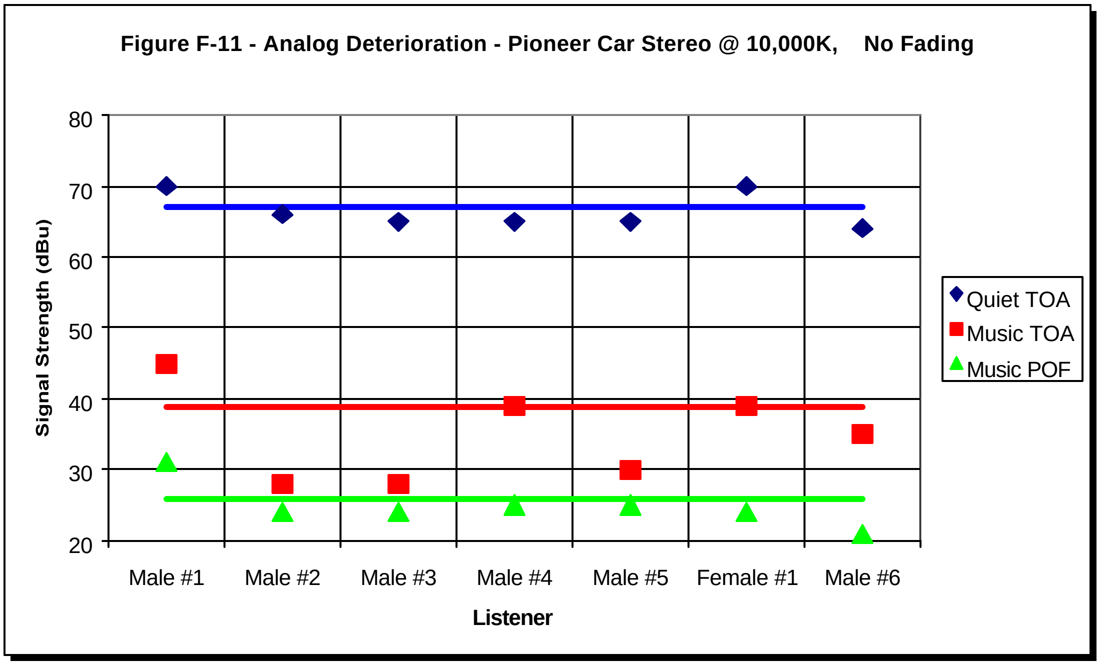


Figure F-11 - Analog Deterioration - Pioneer Car Stereo @ 10,000K, No Fading
Signal Strength (dBu)
80
70
60
50
40
30
20
Male #1
Male #2
Male #3
Male #4
Male #5
Female #1
Male #6
Listener
Quiet TOA
Music TOA
Music POF

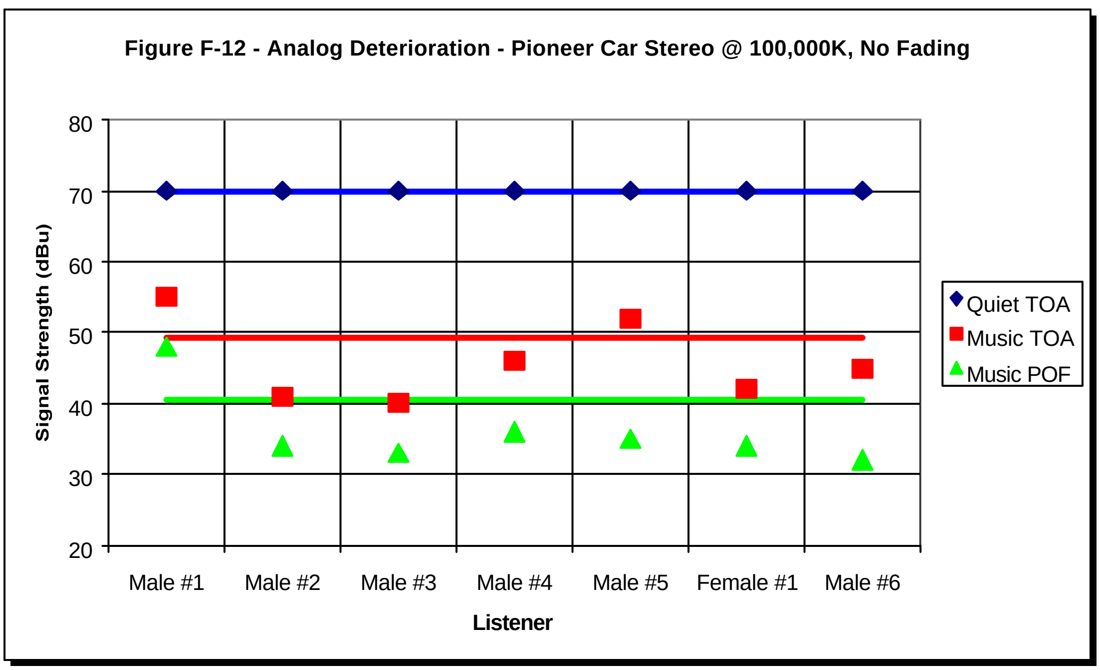


Figure F-12 - Analog Deterioration - Pioneer Car Stereo @ 100,000K, No Fading
Signal Strength (dBu)
80
70
60
50
40
30
20
Male #1
Male #2
Male #3
Male #4
Male #5
Female #1
Male #6
Listener
Quiet TOA
Music TOA
Music POF

Figure F-13 - Analog Deterioration - Pioneer Car Stereo @ 10,000K, 9-Ray UF Fading

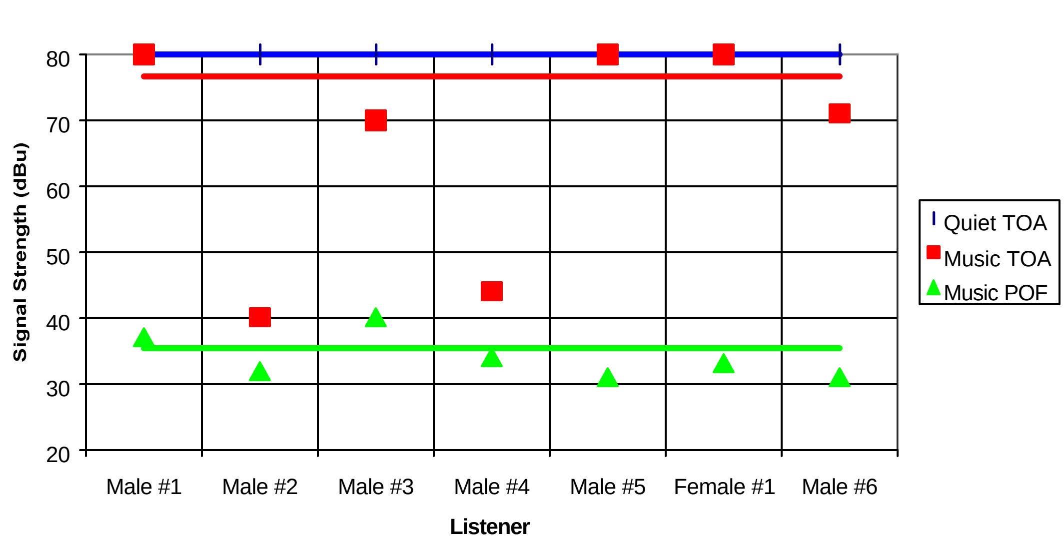
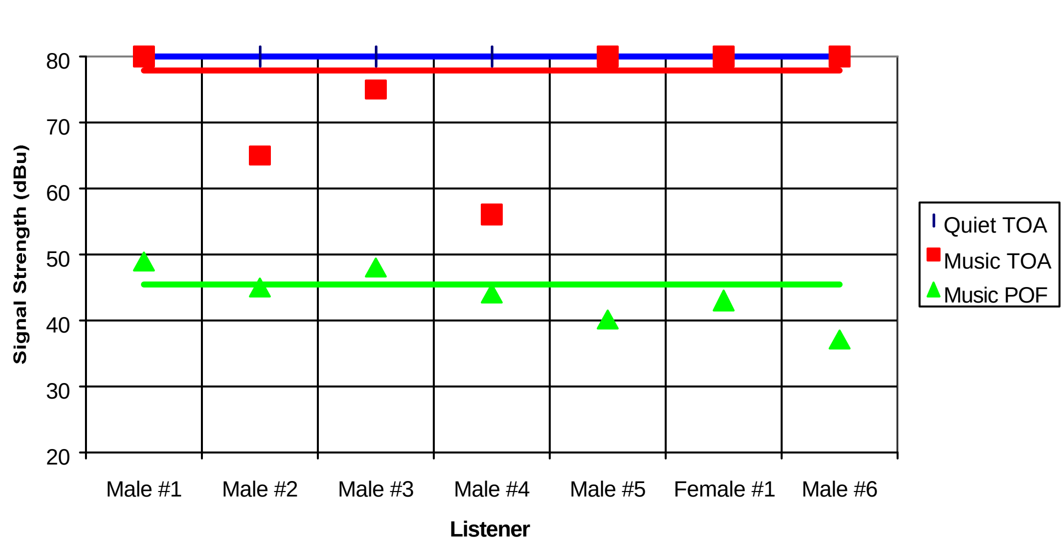


Figure F-14 - Analog Deterioration - Pioneer Car Stereo @ 100,000K, 9-Ray UF Fade



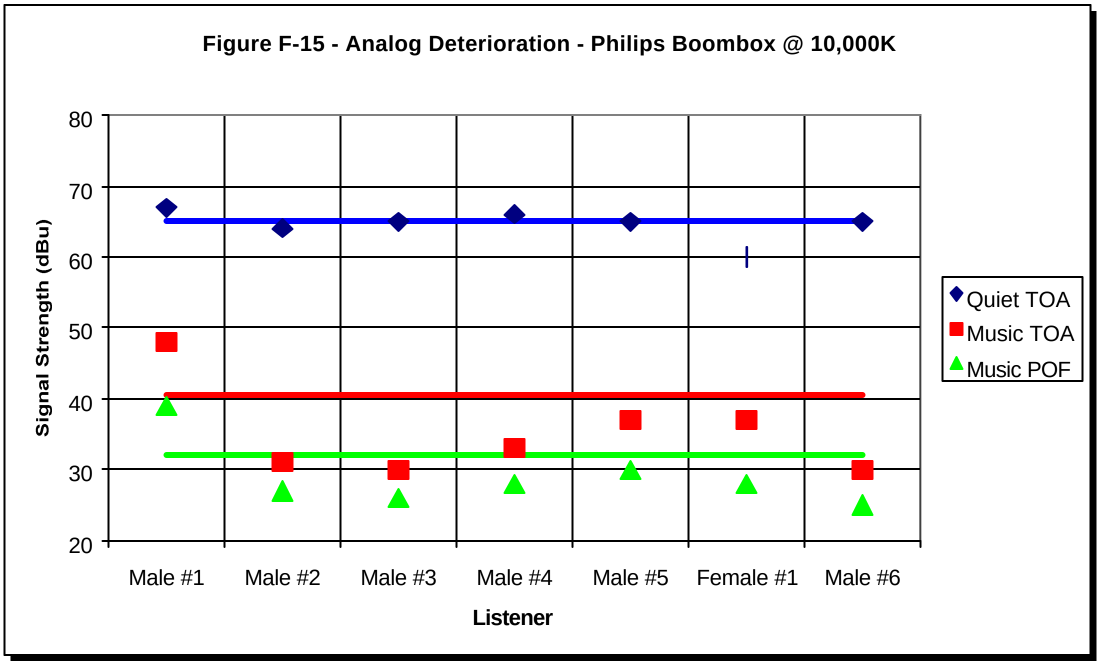


Figure F-15 - Analog Deterioration - Philips Boombox @ 10,000K
80
70
60
50
40
30
20
Signal Strength (dBu)
Male #1
Male #2
Male #3
Male #4
Male #5
Female #1
Male #6
Listener
Quiet TOA
Music TOA
Music POF

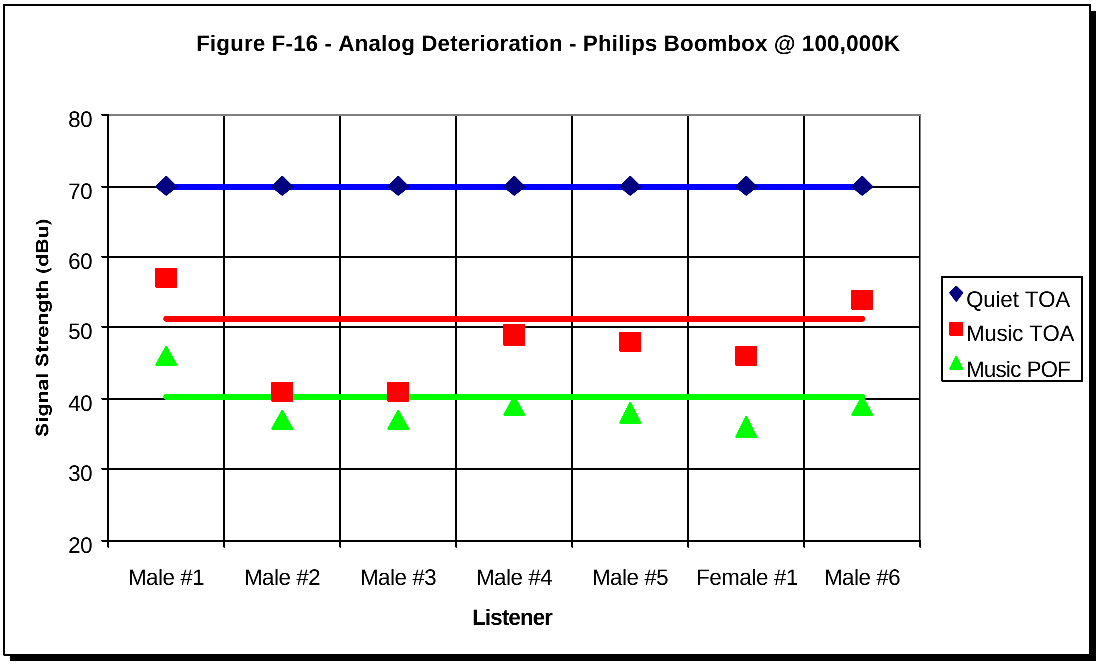
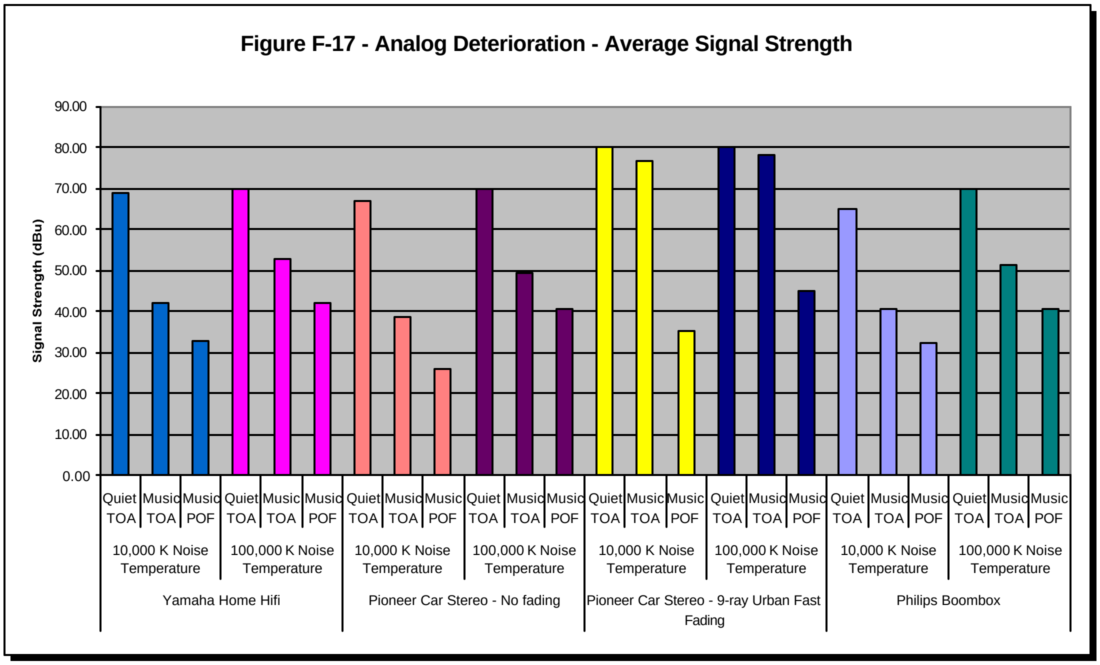


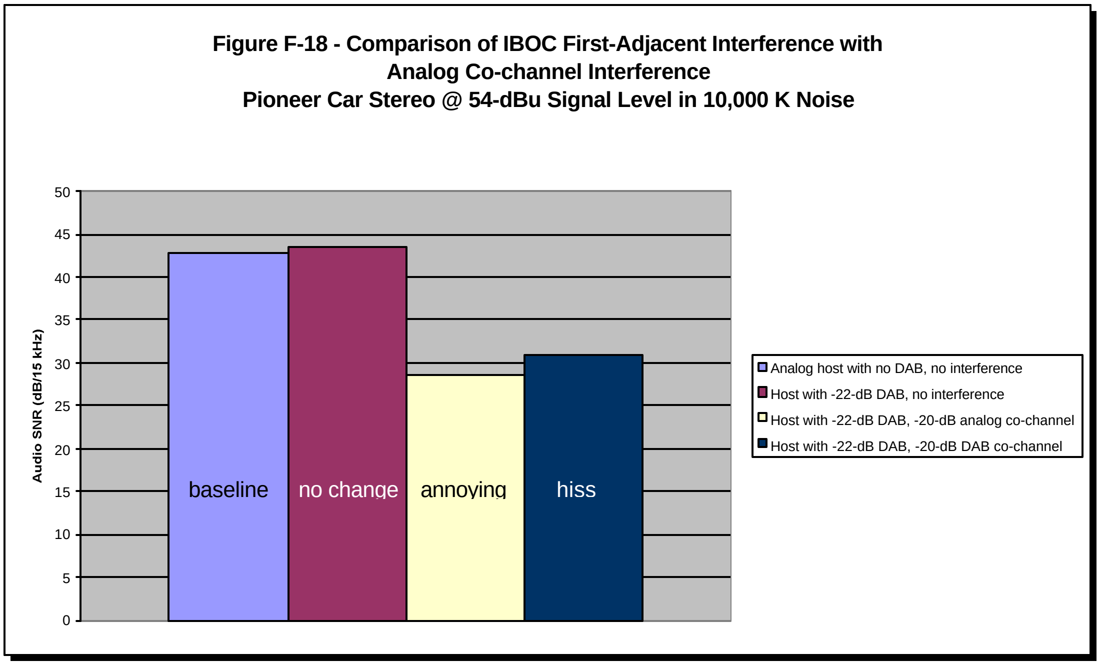
Figure F-16 - Analog Deterioration - Philips Boombox @ 100,000K
80
70
60
50
40
30
20
Signal Strength (dBu)
Male #1
Male #2
Male #3
Male #4
Male #5
Female #1
Male #6
Listener
Quiet TOA
Music TOA
Music POF



3.2. Comparison of Analog Co-Channel and Digital First Adjacent Interference

Perhaps the most significant challenge to the compatibility of IBOC signals is the interference introduced into analog signals by IBOC first adjacents. Co-channel interference at a station's protected contour is limited by FCC rule: its power must be at least 20 dB below that of the desired FM signal. Since the DAB sideband from a first adjacent channel is essentially co-channel interference to the desired FM signal, this test investigates the resulting interference if the power in the DAB sidebands of a –6 dB first adjacent interferer is raised to the maximum co-channel level.

For the car stereo at a 54 dBu signal level in a 10,000K noise environment, the test measured the degradation to the desired analog signal introduced by a –20 dB analog co-channel, and compared it to the degradation introduced by a –6 dB first adjacent hybrid IBOC signal with total DAB power of –11 dB_{host}. Figure F-18 shows the analog audio SNR of the desired signal, alone and with each interferer, and the subjective audibility of the interference (which is written on each bar graph).



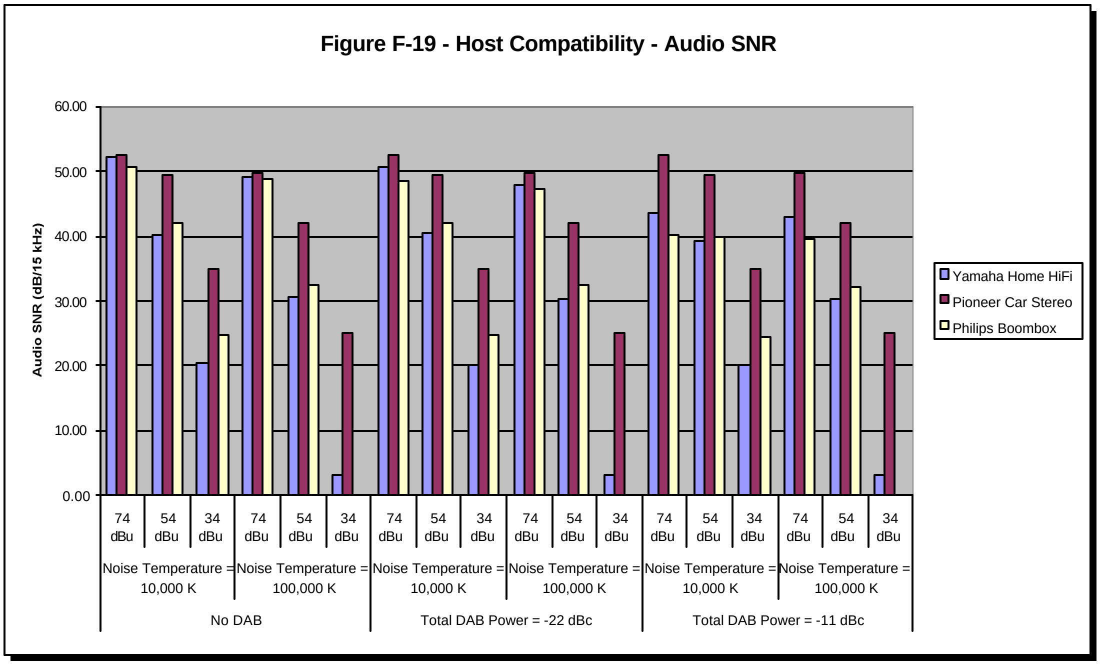
Not only does the existing analog co-channel interference degrade the audio SNR by 3 dB more than the first adjacent DAB at –11dB$_{host}$, the subjective audio quality is much worse. The analog co-channel produced an annoying dynamic noise modulation that varied with the audio content of the co-channel, while the DAB first adjacent introduced an audible, steady hiss which was much more tolerable.

This test indicates that increasing DAB power by 11 dB over the baseline will introduce interference from first adjacent IBOC signals that is no more severe than that currently allowed by existing FCC rules for analog co-channels. As a result, more detailed tests were performed to investigate the compatibility of not only *baseline IBOC* signals, but also IBOC signals with increased power in the digital sidebands. The results of these tests are documented below.

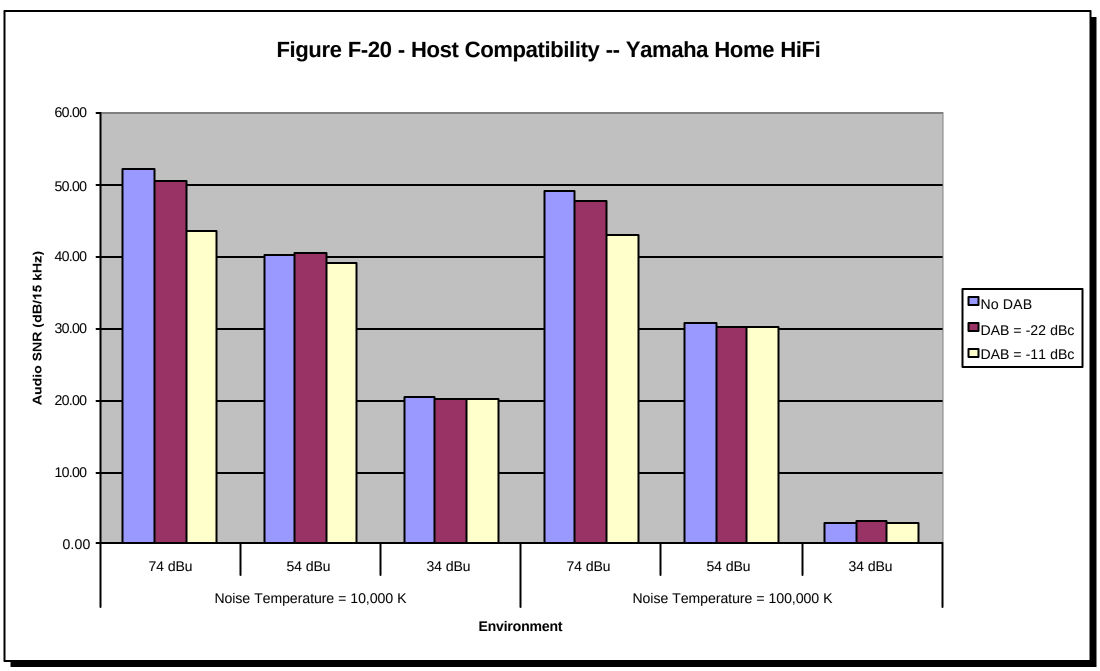
3.3. Host Compatibility

While DAB power should be maximized to provide robust digital coverage, it must not be increased to the detriment of existing analog signals. This test investigates one aspect of analog compatibility by measuring the degradation introduced to the host analog signal by its IBOC DAB sidebands. Besides measuring the analog audio SNR of a *baseline IBOC* signal, the test also finds the levels of the DAB sidebands at which the candidate receivers begin to degrade and fail.

Figure F-19 shows the audio SNR of all receivers at 74, 54, and 34 dBu signal levels in 10,000K and 100,000K noise environments for cases with no DAB, baseline –22dB$_{host}$ DAB, and –11 dB$_{host}$ DAB.



Figures F-20 through F-22 show the audio SNR of each individual receiver at 74, 54, and 34 dBu signal levels in 10,000K and 100,000K noise environments for cases with no DAB, baseline –22dB$_{host}$ DAB, and –11 dB$_{host}$ DAB.



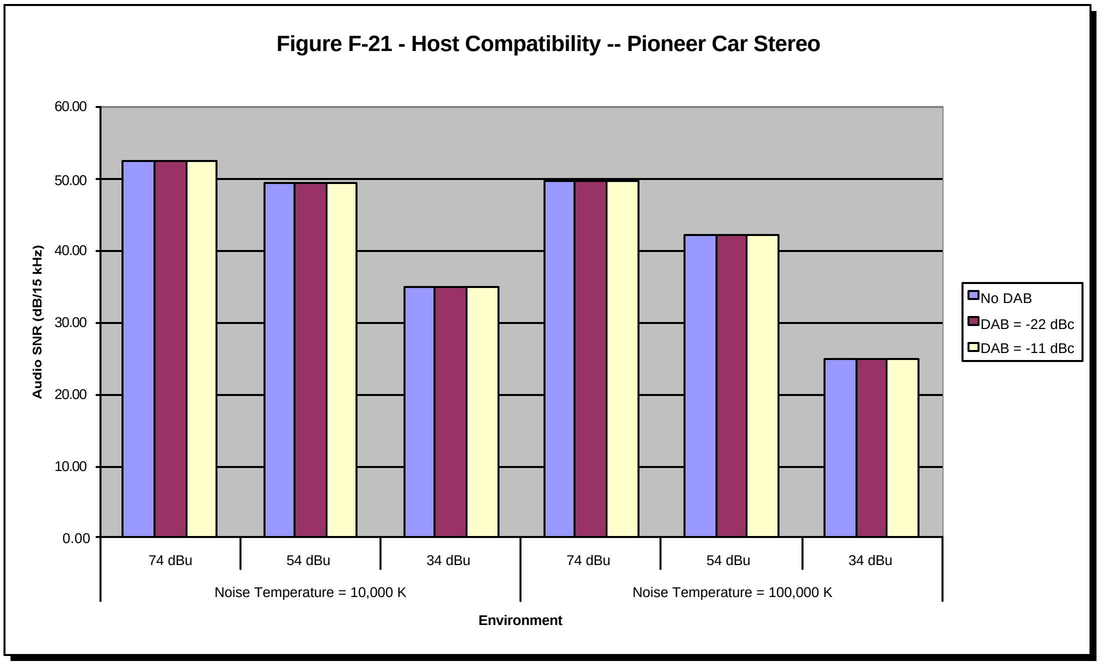


Figure F-21 - Host Compatibility -- Pioneer Car Stereo
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Audio SNR (dB/15 kHz)
74 dBu
54 dBu
34 dBu
74 dBu
54 dBu
34 dBu
Noise Temperature = 10,000 K
Noise Temperature = 100,000 K
Environment
No DAB
DAB = -22 dBc
DAB = -11 dBc

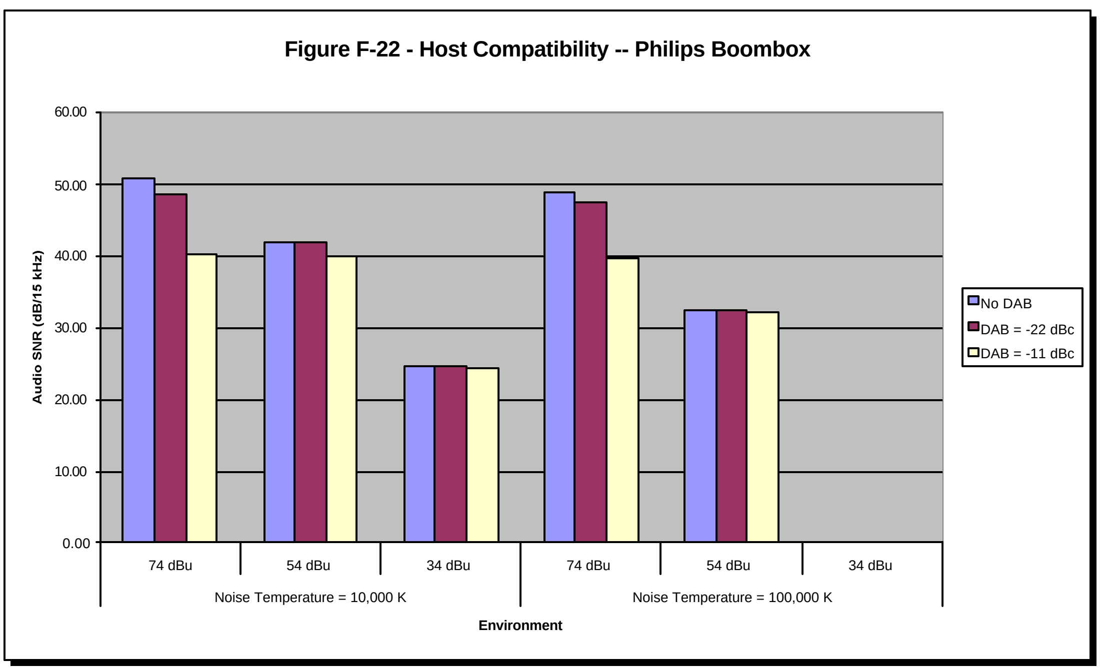


Figure F-22 - Host Compatibility -- Philips Boombox
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Audio SNR (dB/15 kHz)
74 dBu
54 dBu
34 dBu
74 dBu
54 dBu
34 dBu
Noise Temperature = 10,000 K
Noise Temperature = 100,000 K
Environment
No DAB
DAB = -22 dBc
DAB = -11 dBc

The relative differences in audio SNR in Figures F-19 through F-22 provide valuable insight into compatibility of the DAB sidebands with the host analog FM signal. First, the relatively high audio SNRs of the car stereo indicate that it performs consistently better than the boombox and home HiFi, presumably because of superior filtering. In fact, at a 34 dBu signal level with 100,000K noise, both the home HiFi and boombox exhibit signal mutilation due to operation below demodulator threshold. Second, as expected, audio SNR decreases on all receivers with increased noise or decreased signal.

Figure F-21 clearly shows that the car stereo is unaffected by the addition of DAB at any level, regardless of the signal level or environment. Figures F-20 and F-22 likewise indicate that the impact of adding –22 dB_{host} baseline DAB is negligible for the home HiFi and boombox.

Figures F-20 and F-22 indicate a degradation in audio SNR when the power in the DAB sidebands is increased to –11 dB_{host}. In isolation, this might discourage an increase in DAB power aimed at expanding digital coverage. However, when couched within the results of subjective testing, a quite different conclusion may be drawn. Figure F-23 shows the levels of the DAB sidebands at which TOA and POF are reached in quiet and music conditions for all three test receivers in various signal and noise environments.[9]

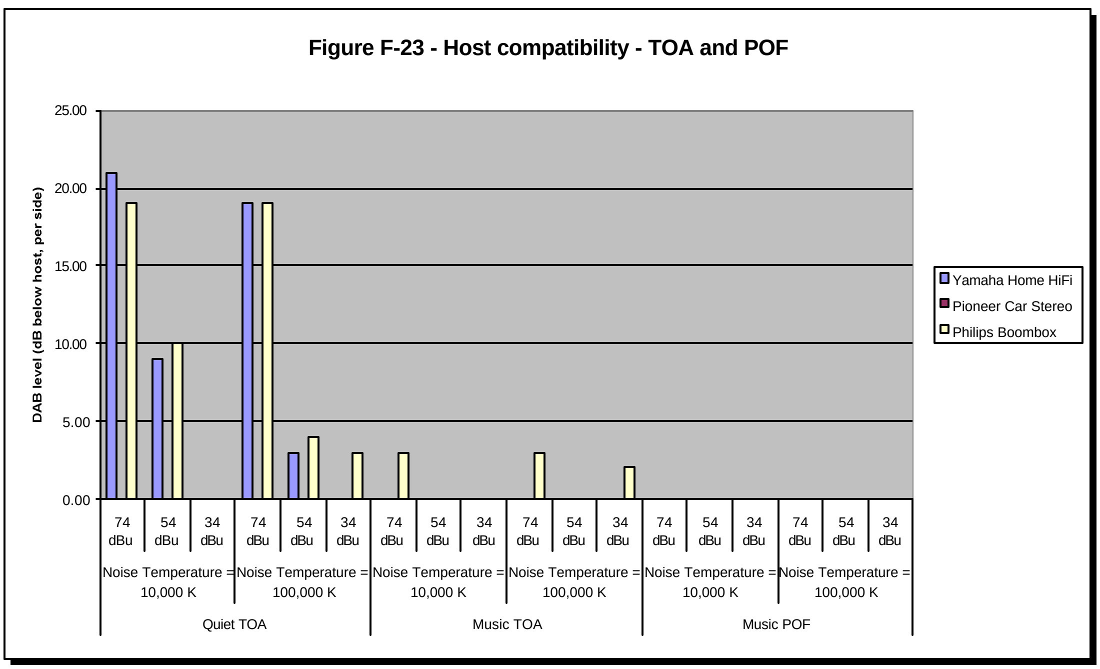


Figure F-23 shows that, even in quiet conditions, *the addition of baseline DAB to the host FM signal has no audible impact on the listening experience*[10]. More significantly, even though an 11 dB increase over the *baseline DAB* level causes an

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[9] Note that the DAB levels shown on Figure F-23 are *per sideband;* -25 dB_{host} per sideband corresponds to –22 dB_{host} baseline DAB.

[10] This has been verified in USADR field tests. Refer to Appendix H.

audible noise increase *in silence* on the boombox and home hiFi, the effect is completely masked when audio is present. As a result, an increase in DAB power from –22 dB_{host} to –11dB_{host} should not appreciably degrade the host FM signal.

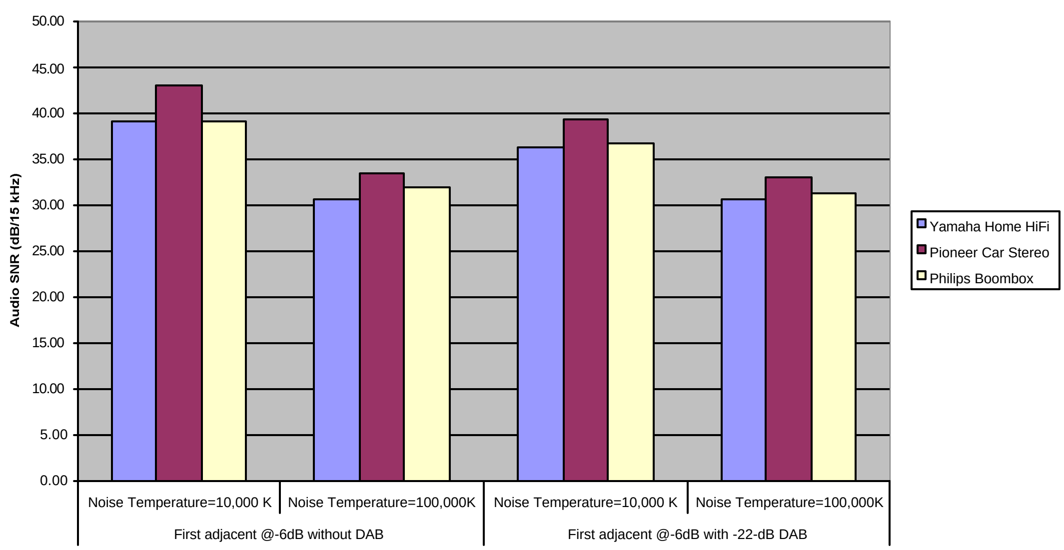
3.4. First Adjacent Compatibility

Since DAB sidebands lie under the host station's first adjacent analog signal, this is perhaps the most important compatibility test. Maximizing DAB power to improve digital coverage has a direct impact on the performance of the first adjacent analog signal.

This test measures the degradation introduced to the desired analog signal by first adjacent IBOC DAB sidebands. Besides measuring the analog audio SNR of a desired *baseline IBOC* signal in the presence of a *baseline IBOC* first adjacent, the test also finds the levels of the first adjacent DAB sidebands at which the candidate receivers begin to degrade and fail.

Figure F-24 shows the audio SNR of all receivers at a 54 dBu signal level in 10,000K and 100,000K noise environments with –6 dB_{host} first adjacents with no DAB, and with baseline –22dB_{host} DAB.

Figure F-24 - First-Adjacent Compatibility - Audio SNR at 54-dBu Signal Level



Figures F-25 through F-27 show the audio SNR of each individual receiver at a 54 dBu signal level in 10,000K and 100,000K noise environments with –6 dB_{host} first adjacents with no DAB, and with baseline –22dB_{host} DAB.

Figure F-25 - First-adjacent Compatibility -- Yamaha Home HiFi at 54-dBu Signal Level

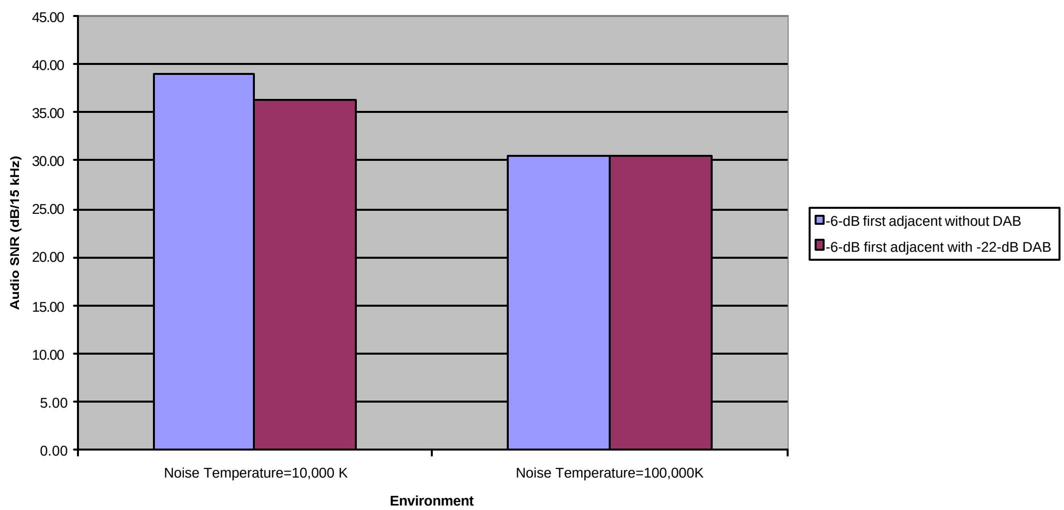


Figure F-26 - First-adjacent Compatibility -- Pioneer Car Stereo at 54-dBu Signal Level

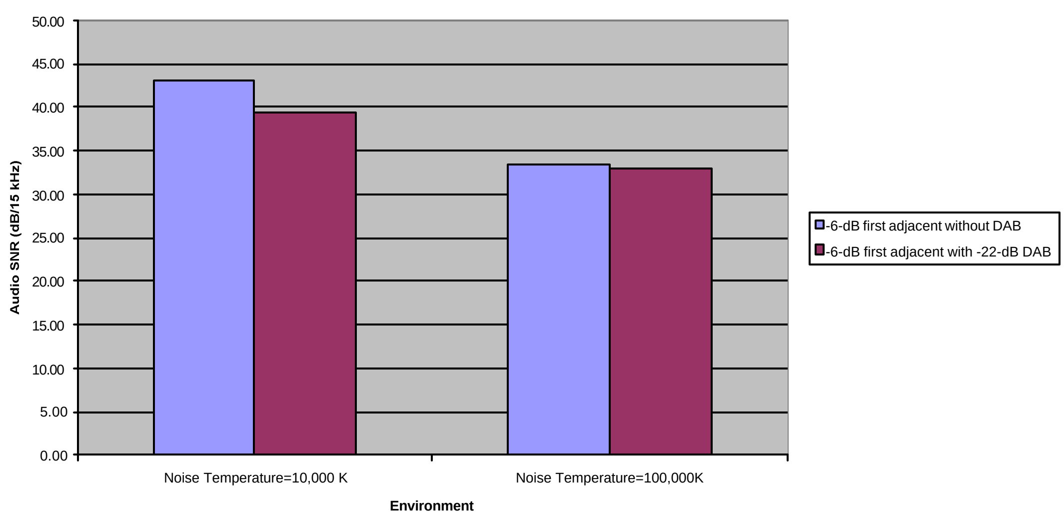
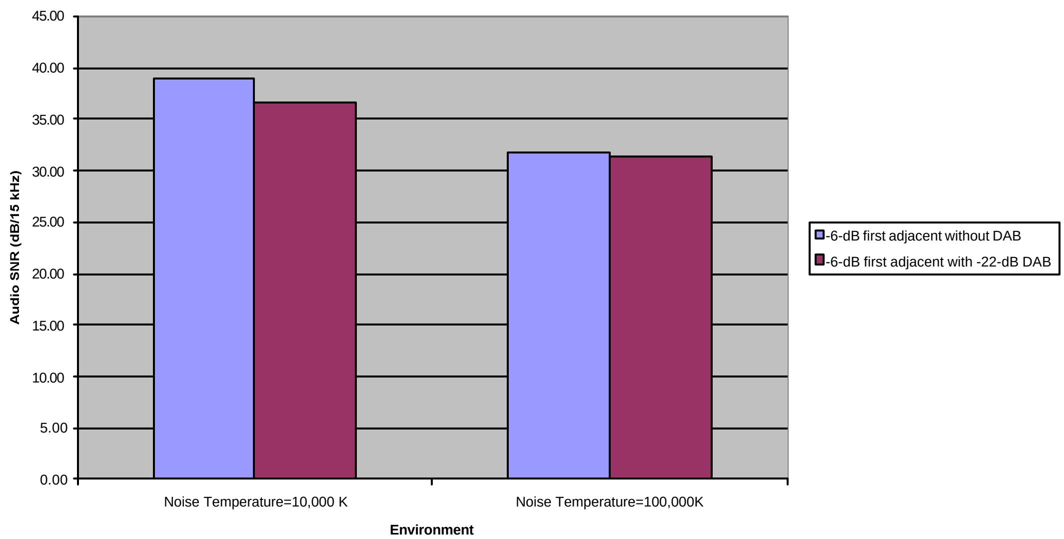


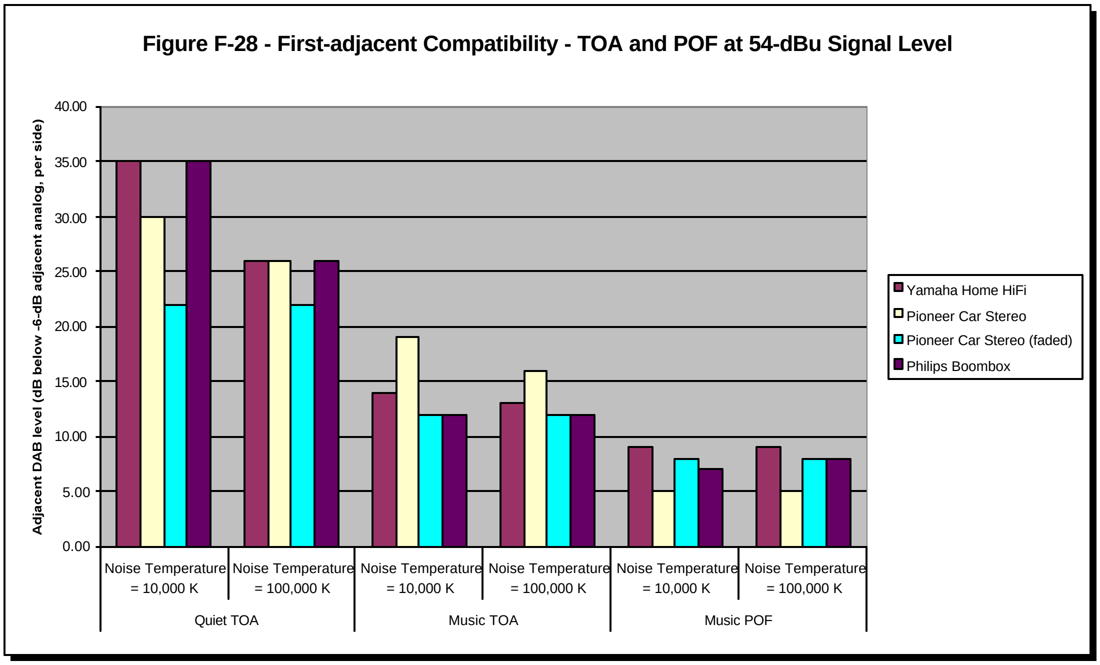
Figure F-27 - First-adjacent Compatibility -- Philips Boombox at 54-dBu Signal Level



The relative differences in audio SNR in Figures F-24 through F-27 allow insight into compatibility of the first adjacent DAB sidebands with the desired analog FM signal. The host compatibility tests indicate that better filtering in the car stereo results in better immunity to noise induced by DAB sidebands. However, Figures F-25 through F-27 show that the car stereo holds no clear advantage in rejection of first adjacent DAB sidebands, due to their spectral occupancy under the desired channel. In fact, Figures F-25 through F-27 indicate that the introduction of baseline (-22 dB_{host}) DAB to a –6 dB_{host} first adjacent channel has very little effect on audio SNR of the desired analog signal (less than 3 dB in even the cleanest environment), regardless of the receiver. Clearly, degradation due to *existing* forces, such as noise and the analog portion of first adjacents, dominates over any additional noise added by *baseline DAB*. This finding was further validated in subjective audio tests, which showed that, with audio on the desired channel, the addition of *baseline DAB* to a –6 dB_{host} first adjacent is inaudible.

In an effort to extend digital coverage, the DAB power may be raised significantly over baseline levels. The impact of increasing DAB power on first adjacent compatibility has been investigated using subjective audio tests, which record the levels of the first adjacent DAB sidebands at which the TOA and POF are reached for each of the receivers, with both quiet and baseline (music) desired FM signals.

Figure F-28 shows the levels of the first adjacent DAB sidebands relative to a –6 dB analog first adjacent, at which TOA and POF are reached in quiet and music conditions for all three test receivers at a 54 dBu signal level in 10,000K and 100,000K noise environments. Figures F-29 through F-31 show the information of Figure F-28 for each individual receiver.[11]



Figures F-29 and F-31 show that, even with an 11 dB increase in DAB signal power over the baseline level, the first adjacent DAB does not audibly degrade the desired signal when audio is present on the home HiFi and boombox. However, degradation in the non-faded car stereo, shown in Figure F-30, does occur after just a 6 dB increase in signal power at a 54 dBu signal level. It should be noted that this test was performed in a quiet audio laboratory, with A/B testing; the DAB would actually be much more difficult to perceive in the noisy environment of a fielded car stereo.[12] Therefore, an 11 dB increase in the level of the DAB sidebands to –11 dB_{host} would probably not cause noticeable interference to first adjacent desired analog signals.

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11 Note that the DAB levels shown in these figures are *per sideband;* -25 dB_{host} per sideband corresponds to –22 dB_{host} baseline DAB.

12 This assertion has been validated by USADR field testing.

Figure F-29 - First-adjacent Compatibility - Yamaha Home HiFi - TOA and POF at 54-dBu Signal Level

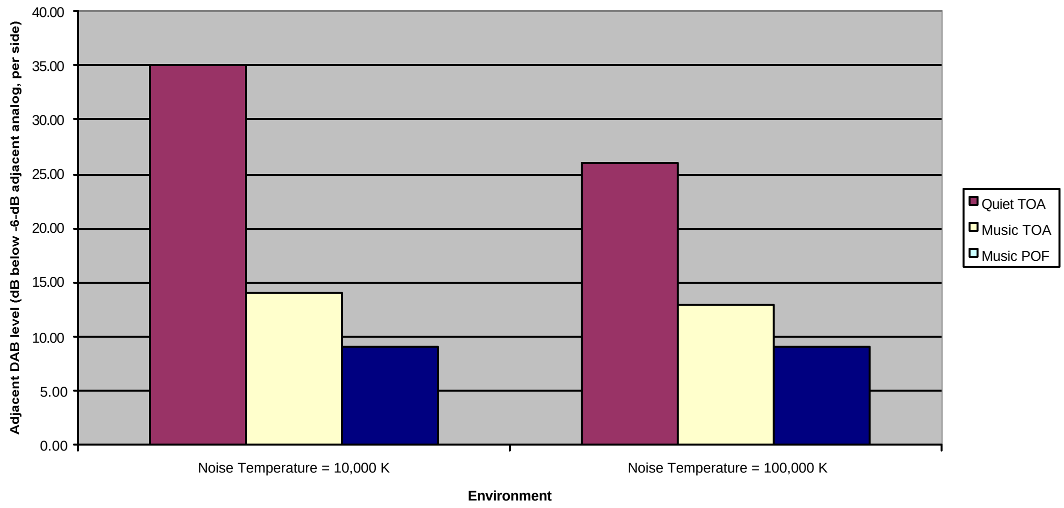
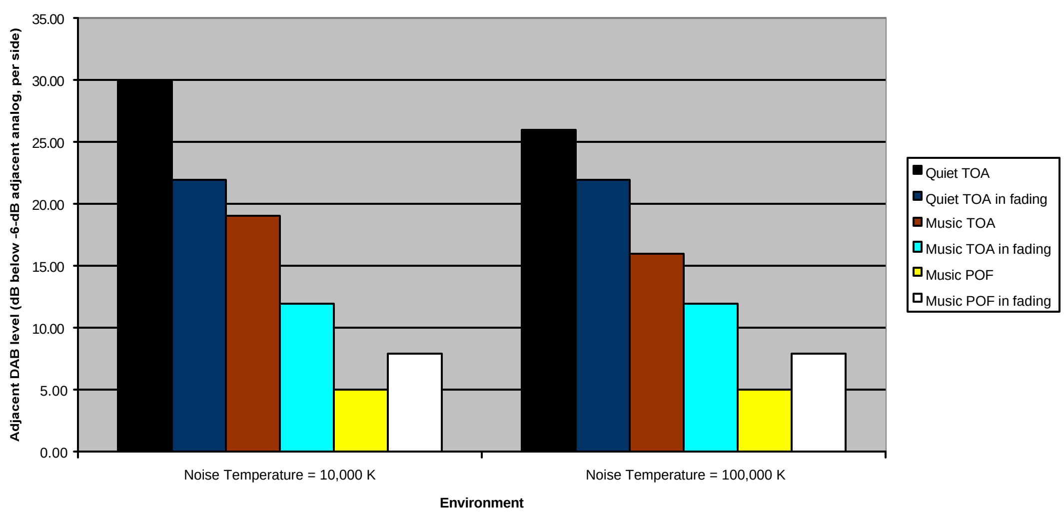
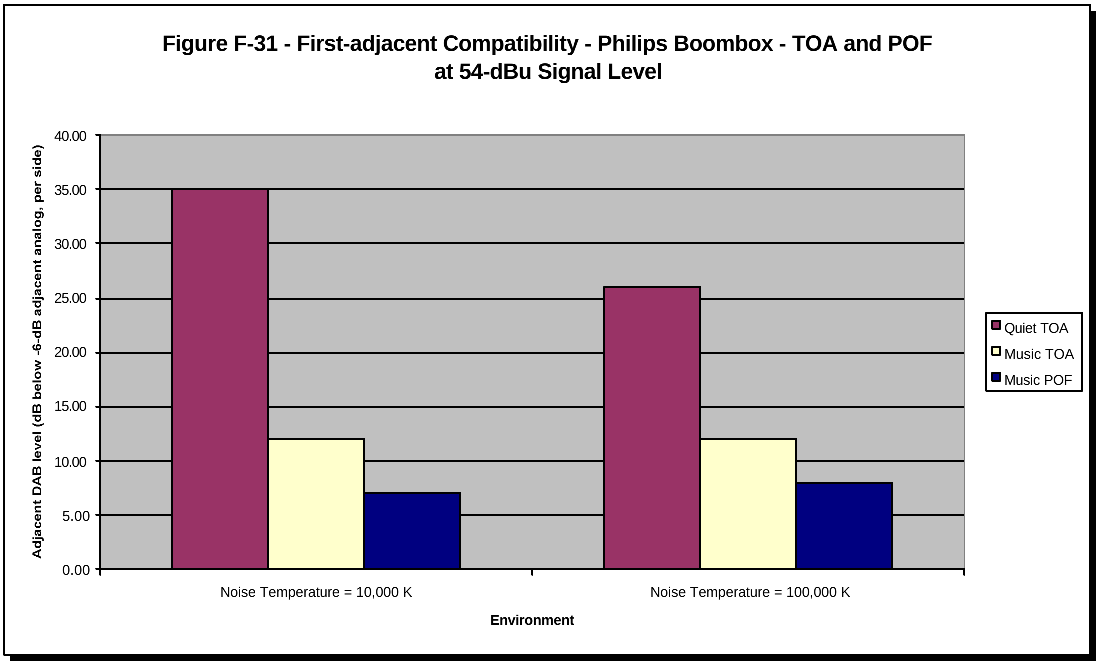


Figure F-30 - First-adjacent Compatibility - Pioneer Car Stereo - TOA and POF at 54-dBu Signal Level





4. Summary and Conclusions

USADR has carefully studied the compatibility of IBOC DAB signals with existing analog service. Laboratory tests were performed to measure the degradation of an analog FM signal in the presence of hybrid IBOC signals of various levels in a number of environments. The results of these tests are summarized below.

- Increasing DAB power by 11 dB over the baseline will introduce interference from first adjacent IBOC signals that is no more severe than that currently allowed by existing FCC rules for analog co-channels.

- Baseline (-22 dB_{host}) DAB sidebands were found to have no audible effect on the host analog. When the DAB sidebands are increased by 11 dB, any resultant degradation in audio SNR is masked by host audio.

- The introduction of baseline (-22 dB_{host}) DAB to a –6 dB first adjacent channel has a minor effect on audio SNR of the desired analog signal at a 54 dBu signal level. This effect is inaudible with audio on the desired channel, since degradation due to *existing* forces dominates over any additional noise added by *baseline DAB*. When DAB sidebands were increased by 11 dB, degradation (with desired audio) was detected only on the car stereo. Typically noisy driving environments may make this degradation difficult to perceive.

These results indicate that the addition of *baseline DAB* to analog signals has a negligible effect on existing analog service.[13]

[13] This conclusion has been validated by USADR field tests. Refer to Appendix H.